Passive Sampling of Ambient Concentrations of Volatile Organic Compounds in the Greater New Orleans Area in the Aftermath of Hurricane Katrina

Final Report

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Contract Number EP-D05-065
Work Assignment 26

June 30, 2006

Acknowledgements/Disclaimer

This project was funded by Environmental Protection Agency (EPA)/Federal Emergency Management Agency (FEMA). We thank the State of Louisiana Department of Environmental Quality (LDEQ) for providing assistance for field sampling and access to their monitoring sites. EPA/Region 6 managed the project described here under contract EP-D05-065 to Alion Science and Technology with subcontract to University of Texas, Health Science Center at Houston, School of Public Health. The statements and conclusions in this report are not necessarily those of the Environmental Protection Agency or their employees. The use or mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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Table of Contents

List of Figures

List of Tables

I. Introduction

On August 29, 2005 Hurricane Katrina struck the city of New Orleans, Louisiana and the surrounding area with devastating force and consequences. In addition to the direct effects of the powerful storm's winds and rain, the hurricane caused the failure of levees in five places on three different canals within New Orleans. This caused extensive flooding, so that most of the city was under water. The catastrophe of Hurricane Katrina resulted in widespread, severe damage to much of the greater New Orleans area's buildings and infrastructure.

Among the many issues raised by the storm's aftermath was the question of air quality. There was much concern that the wind and flood damage might have caused spills or created conditions ripe for the ongoing release of many hazardous air pollutants from fuels, other petroleum-related products, and other chemicals. In addition, there was the worry that subsequent burning of debris from the clean-up efforts could also be a source of hazardous air pollutants. (Later, a determination was made that landfill disposal, rather than burning, would be used.)

In response to these air quality concerns, the Environmental Protection Agency's (EPA) Region 6 instituted an emergency air quality monitoring network in the greater New Orleans area. Due to the widespread lack of power and the difficulty of accessing much of the area, part of the air quality sampling effort included the deployment of passive sampling devices.

II. Site locations

Originally, twenty sites in the greater New Orleans area were considered as locations for passive air sampling devices. In the end, eighteen sites were actually employed. Table 1 identifies these sites by a number, name, and parish. Because some of the originally considered sites were not used, the site numbers are not consecutive.

The site locations are displayed in Figure 1, along with the locations of the levee breaks. The breaches occurred at two points on the Industrial Canal in the eastern area of the city, two places on the London Avenue Canal in the north-central part of New Orleans, and on the 17th Street Canal near sampling site 12, the Bucktown Coast Guard Station. Figure 1 also shows salient features of the area including water bodies and waterways (in particular, Lake Ponchartrain and the Mississippi River), municipal areas, major roads, the Lake Ponchartrain Causeway, and airports. In addition, Figure 1 also indicates how the greater New Orleans area was divided into four sections for data comparison purposes. (See Section IV.)

As part of this project, Alion Science and Technology (Alion) subcontracted with the University of Texas Health Science Center at Houston, School of Public Health (UTSPH). The UTSPH principal investigator, Dr. Thomas Stock, made visits to the sampling sites as part of the overall quality assurance procedures. For this purpose, Dr. Stock traveled to New Orleans on two occasions in 2005, November 20-21 and December 19.

During his site visits, he made various notations about anything that might have the potential to affect sample quality, such as sampler positioning at the site and activities near the site that might influence the air quality reported from the site. The sites were also photographically documented. Pictures of each site were taken facing in all four major

compass directions; in addition, photos were made of any other aspect of the site and its immediate environs that might affect sample quality. Dr. Stock's observations and general site descriptions follow Table 1 and Figure 1. In these descriptions, Dr. Stock occasionally refers to certain specific pictures using the site identifier from the project (*e. g.*, AS001); for this report, only the numbers are used to uniquely reference each site. The photographs taken by Dr. Stock accompany this report in a separate electronic file with each site's photographs stored in a separate folder; all are stored as .jpg files.

Table 1. Post-Hurricane Katrina passive sampling sites in the New Orleans area.

Site number	**Site name**	**Parish**
1	Municipal Training Academy	Orleans
3	Arabi	St. Bernard
4	Meraux	St. Bernard
5	Coast Guard Reserve	Plaquemines
6	Kenner	Jefferson
7	Luling	St. Charles
8	New Orleans City Park	Orleans
9	Marrero	Jefferson
10	University of New Orleans	Orleans
11	French Market	Orleans
12	Bucktown Coast Guard Station	Jefferson
13	La Freniere Park	Jefferson
14	New Orleans Water Purification Plant	Orleans
15	KAWK Park	Jefferson
16	Fort McComb State Monument	Orleans
17	Fort Pike State Historic Site	Orleans
18	Slidell Wastewater Treatment Plant	St. Tammany
20	Camp Villere National Guard Training Center	St. Tammany

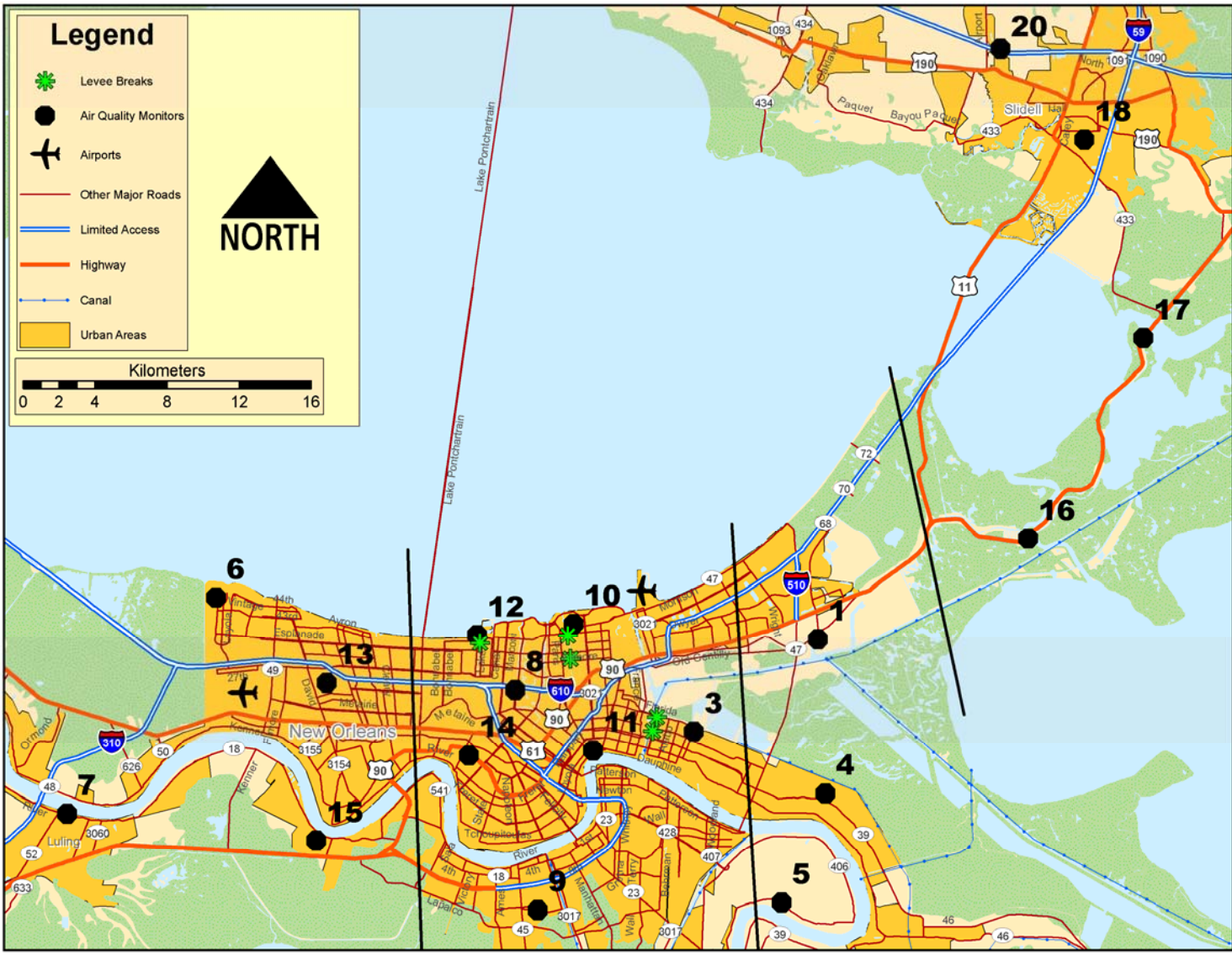

Figure 1. Greater New Orleans post-Hurricane Katrina passive sampling sites.

Site 1 – Municipal Training Academy

This site was at a firefighter training academy. Sampling occurred on a raised wooden platform located in a small field not far from a parking lot and some buildings. Field personnel reported sometimes observing combustion plumes from test burns from a facility east of the site (the red building seen in the distance in photo AS001-2). During this visit, the OVM was attached to one of the tripods supporting other air sampling equipment.

Site 3 - Arabi

This site was in St. Bernard Parish, in an area severely devastated by the hurricane. Sampling occurred on a raised wooden platform, secured behind a fence, located near one end of a large field near a school. The site was almost completely surrounded by parked, inoperable school buses. Nearby was the central school bus maintenance facility for the local school district. Bags of disposed materials from this maintenance facility were observed (photos AS003-2 and AS003-3). Field personnel reported remediation activities occurring at the nearby school, including the use of heavy equipment. During this visit, the OVM was not observed; later communication with field personnel indicated the OVM was placed outside the secured area. The OVM can be observed in the same two photos noted above when enlarged, attached horizontally to the bottom of an electrical box mounted on the utility pole.

Site 4 - Meraux

This site was another location in St. Bernard Parish, also in a devastated area. Sampling occurred on a raised wooden platform, secured behind a fence, at the end of an open field, surrounded by streets with flood-destroyed homes. Field personnel reported debris clean-up activities at a nearby school. A noticeable smell was present in the area, probably best described as a mix of petroleum and sea water odors. During this visit the OVM was not observed; however, it was likely placed in a similar position as for Site AS003.

Site 5 - Coast Guard Reserve

This site was at a U.S. Coast Guard Reserve facility near the Mississippi River, southeast of the city. Sampling occurred on a raised wooden platform, secured behind a fence, in a grassy area across a service road from the lone Coast Guard office building (east of the site). A swampy area was to the southwest of the site. About 50 m to the west of this site was a wood chipper and high-temperature incinerator unit in operation. Two pictures of this are included in this site's folder. The OVM was hung in a protected position beneath a piece of plywood added to a corner of the platform rail.

Site 6 - Kenner

This site was a Louisiana Department of Environmental Quality (LDEQ) air monitoring station that was undamaged by the hurricane. Sampling occurred on a raised sampling platform (higher than others), secured behind a fence, and close to a trailer serving as a field office, with the door side of the office closest to the platform. Housing was located to the east and south; large grassy areas were to the north and west. A power distribution center was located to the NNW (see photo AS006-N); some heavy machinery was operating there during the visit. Three OVMs (2 collocated samples and 1 field blank) were attached vertically to a metal support stand, with no protection from the elements.

Site 7 - Luling

This site was the farthest upriver monitoring site. It was located on the south bank of the Mississippi River, with a fairly busy secondary road (River Road) between the river and the site. Monitoring occurred on a raised platform that had previously been utilized by LDEQ and was secured behind a fence. There was a major Monsanto facility about 1 mile SE of the site. The OVM was hung in a protected position beneath a piece of plywood added to a corner of the platform rail. It was close to a sheet of plastic used to protect sampling pumps.

Site 8 - New Orleans City Park

This site was a large grassy area at the intersection of Marconi Dr. and Florida Blvd., just west of City Park. This was an existing LDEQ air monitoring station and, in a manner similar to Site 6-Kenner, sampling equipment was placed on a raised platform behind a fence. Unlike the Kenner site, the sampling platform was not near the door side of the nearby trailer. Interstate 610 was approximately 180 m north of this site. West of the site (see photo AS008-5) was a staging area for debris cleanup. Some heavy diesel equipment (*e. g.*, cranes) was seen in this area during the visit. Field personnel reported that, previously, many trucks were seen surrounding the site. The OVM was attached in a vertical position to the frame of a particulate matter sampler, with some protection from the elements.

Site 9 - Marrero

This site was a large fenced-in grassy area, under the jurisdiction of a local water utility, with a large water tower on the premises. There were two sampling platforms – the original platform serving as an LDEQ site, and a new platform constructed for the post-Katrina sampling. This was a largely residential area, with the closest homes to the northeast and west. South of the site (see photo AS009-S) some heavy equipment was observed working on improvements to the Patriot St. Canal. Positions of the three OVMs were similar to those observed at the Kenner site, with no protection from the elements.

Site 10 - University of New Orleans

This site was on the campus of the University of New Orleans, in the northern part of the city, not far from Lake Pontchartrain. At the time of the visit, all visitors had to pass a manned security checkpoint at the entrance to the campus. Sampling occurred on a raised wooden platform, with no security fence. The location was near a central utility plant with a cooling tower. Not much activity was observed during this visit. A few parked pick-up trucks were nearby. The OVM was attached to a tripod, with no protection from the elements. No other air sampling occurred during the visit.

Site 11 - French Market

This site was located in the corner of a small parking lot near the intersection of Elysian Fields Ave. and Decatur St., at the east end of the French Market area. Sampling occurred on a raised wooden platform, secured behind a fence. It is likely that automotive emissions would impact measurements at this site. It was uncertain whether the parking lot was open for business. The OVM was attached to a sampling stand in a horizontal position, with the front side down. This is the recommended position if there is no available protection from the elements.

Site 12 - Bucktown Coast Guard Station

This site was on the premises of an active Coast Guard station located on the south shore of Lake Pontchartrain, near the 17th St. Canal. This was a secure area. Sampling occurred near the main building, on a concrete pad under a large radio tower. Directly north of the site was a fuel storage area and boat refueling operations (photos AS012-3, -5 and -N). Coast Guard personnel indicated boat refueling occurred approximately twice a day, using mostly diesel, but also some gasoline. Thus, fuel vapors were expected to strongly influence measurements at this site. The OVM was attached to a tripod, with no protection from the elements. No other air quality sampling was occurring.

Site 13 - LaFreniere Park

This site was near a lake in the middle of the park. Open grassy areas surrounded the site. Sampling occurred on a raised wooden platform, secured behind a fence. Although a protective piece of plywood had been installed on a corner of the platform railing, no OVM was observed hanging here. It was later reported from the field that the OVM was hung close to a nearby building (see photo AS013-E). Since there were also field observations of smoking occurring near this building, the representativeness of the relocated sampler may be questioned. It is unknown how many OVM samples were taken at the platform *vs.* near the building.

Site 14 - New Orleans Water Purification Plant

This site was a large municipal drinking water treatment plant, which was a secure area. Sampling occurred on concrete walkways between treatment (clarifying) ponds. A major thoroughfare, S. Claibourne Ave., was approximately 50 m to the northeast. Field personnel indicated that the exact sampling location had recently been moved. The OVM was attached to a particulate matter sampler in a horizontal position, with the front side down.

Site 15 - KAWK Park

This site was at the south corner of a neighborhood park, with open grassy fields to the north and east, and houses to the south and west. This appeared to be a quiet residential area, with only minimal neighborhood street traffic. Sampling occurred on a raised wooden platform, secured behind a fence. The directional photos were taken during the first visit, before active sampling was initiated. A shipyard and railroad terminal were located about 1.5 miles east, and the Mississippi River was approximately 0.3 mile north of this site. During the revisit, no OVM sample was seen.

Site 16 - Fort McComb State Monument

This site was in a very isolated area, along Chef Menteur Highway (Route 90), near a storm-damaged bridge at Chef Menteur Pass. At the time of the visit, a raised wooden platform had just been constructed, with the construction of a secure fence just begun. Up until the visit, OVM sampling occurred in a partially protected area to the ESE of the platform (see photo AS016-E and close-ups). The OVM was attached horizontally to a plastic band placed around a girder, with the face down. OVM samples were to be moved to the platform when the fence was completed. In the partially covered area and nearby, there was an encampment of several trailers with evidence of cooking activities on grills. Besides the possible impact from activities of the campers, there might be an influence on this site from future bridge repair activities.

Site 17 - Fort Pike State Historic Site

This site was a remote site, also along Route 90, about 8 miles NE of Ft. McComb. It was near the ruins of Ft. Pike, near the open water. Sampling occurred on a raised wooden platform, secured behind a fence. A number of trailers and parked vehicles were nearby. Diesel truck traffic and the operation of a heavy crane was observed west of the site (see photo AS017-W). The OVM was attached vertically to a tripod, with no protection from the elements. There was no other air quality sampling was being conducted during this visit.

Site 18 - Slidell Wastewater Treatment Plant

This site was on the premises of a wastewater treatment plant. The treatment ponds were south of the site, at a considerable distance. Sampling occurred in a grassy area on a raised wooden platform, but there was no fence. This site was in the city of Slidell about 7 miles NNW of Site 17-Ft. Pike. Little activity of any sort was observed around the site.

Site 20 - Camp Villere National Guard Training Center

This site was within a National Guard training center, in a grassy area with a few small buildings nearby. Sampling occurred on a wooden platform without a fence. The site was near the southwest corner of Camp Villere, with I-12 approximately 200 m to the SSW. This site was about 4 miles NW of Site 18-Slidell WWTP. Very little nearby activity was observed. There was a fire fighting training facility in the area, but the level of such activity was not known. The OVM was attached horizontally to a plastic band around a post, with the front facing down.

III. Sampling protocol

As mentioned earlier, the work reported here was part of a larger EPA effort to monitor air quality in the aftermath of Hurricane Katrina. As might be expected, conditions in the area after the hurricane were chaotic. In an attempt to minimize logistical problems, the overall project was conducted under the supervision of EPA Emergency Response Teams; actual field sampling was done by Weston Solutions (Weston) and, to some extent, by personnel from the Louisiana Department of Environmental Quality (LDEQ).

Because of the unreliable nature of power supplies and site access in the post-hurricane conditions, EPA elected to conduct some monitoring using passive samplers. Such samplers need no power supply and may be placed in the field and left unattended until retrieval. Alion was chosen to have primary responsibility for the passive air quality monitoring. As mentioned above, Alion subcontracted with UTSPH to accomplish this work. Chemical analyses were done at UTSPH; in addition, Dr. Stock also played a quality assurance role both with his site visits and in reviewing arriving sample shipments to verify that protocol was being followed in the field. Alion provided quality assurance, data review, reporting, and data analysis functions.

The passive samplers chosen for this project were 3M 3500 Organic Vapor Monitor (OVM) badges. OVMs have been found to be reliable passive samplers in other studies (Chung *et al.*, 2004; Chung *et al.*, 1999; Morandi *et al.*, 1997; Stock *et al.*, 1996). A total of twenty-nine volatile organic compounds (VOCs) were reported from the New Orleans monitoring. These are listed in Table 2 together with the EPA-determined screening levels, where these are available.

Table 2. VOCs monitored in the greater New Orleans area.

Compound	**Screening level (µg/m^3)**
benzene	13
toluene	5000
ethylbenzene	4000
m,p-xylene	3000
o-xylene	3000
methyl tertbutyl ether (MTBE)	2500
methyl ethyl ketone	50000
carbon tetrachloride	200
methylene chloride	1000
trichloroethylene	500
tetrachloroethylene	1200
styrene	10000
naphthalene	30
hexane	2000
pentane	na
nonane	na
decane	na
methylcyclopentane	na
dimethylpentane	na
ethylmethylbenzene	na
1,2,3-trimethylbenzene	na
1,2,4-trimethylbenzene	na
1,3,5-trimethylbenzene	na
chloroform	na
p-dichlorobenzene	na
isoprene	na
α-pinene	na
β-pinene	na
d-limonene	na

The "na" in Table 2 indicates that no screening level has been determined for that chemical. It should be noted that screening levels were established for an hourly time frame.

The first samplers were placed in service on October 24, 2005 and the last samples were removed on February 7, 2006. As was expected due to the nature of the post-hurricane environment, sampling was initiated at different times at different sites.

For logistical reasons, the sampling scheme was changed midway through the project. From October 24, 2005 through December 22, 2005, samples were collected on 72-hour (Monday-Thursday) and 96-hour (Thursday-Monday) time periods. (There was a departure from this during the week of Thanksgiving when samples were collected from Monday-Friday and Friday-Monday.)

A break in the sampling occurred during the Christmas holiday, with sampling stopping on December 22 and resuming on December 30. With the resumption, sampling was changed to an every third day basis. Thus, from December 30, the collected samples could not be aggregated

into weeks. In addition, sampling was discontinued at six sites, and initiated at one new site. Figure 2 displays the sampling time frames at all sites.

Prior to the beginning of sampling, field crews were instructed in the deployment of the passive samplers, sample collection, and sample shipment protocol. Details of these procedures are found in the Quality Assurance Project Plan (QAPP), and more specifically, the Standard Operating Procedures (Appendix A of the QAPP). As new crews rotated into the project, they were informed of the appropriate procedures by those rotating out.

As part of the overall quality assurance for the project, duplicate samples and field blanks were collected at sites 6-Kenner and 9-Marrero. In addition, communication problems in the field led to the collection of two additional duplicate samples, one at 14-New Orleans Water Purification Plant and one at 15-KAWK Park.

Through December 22, LDEQ personnel collected samples at six sites: 3-Arabi, 4-Meraux, 6-Kenner, 8-New Orleans City Park, 9-Marrero, and 14-New Orleans Water Purification Plant. When sampling restarted on December 30, all samples were collected by Weston. As for the new sampling time frame, this change was made as part of the logistical adjustments for the overall project.

As a supplement to this report, all monitoring data from the entire project are being supplied in two electronic formats. An Excel file contains all observations from each site and sampling period on a single worksheet; this file contains additional worksheets with coding and site location information, as well. All these data have previously been supplied to EPA in separate weekly transmissions through the course of the project. In addition to the Excel file, the entire set of monitoring data is also being furnished in the form of a SAS data set.

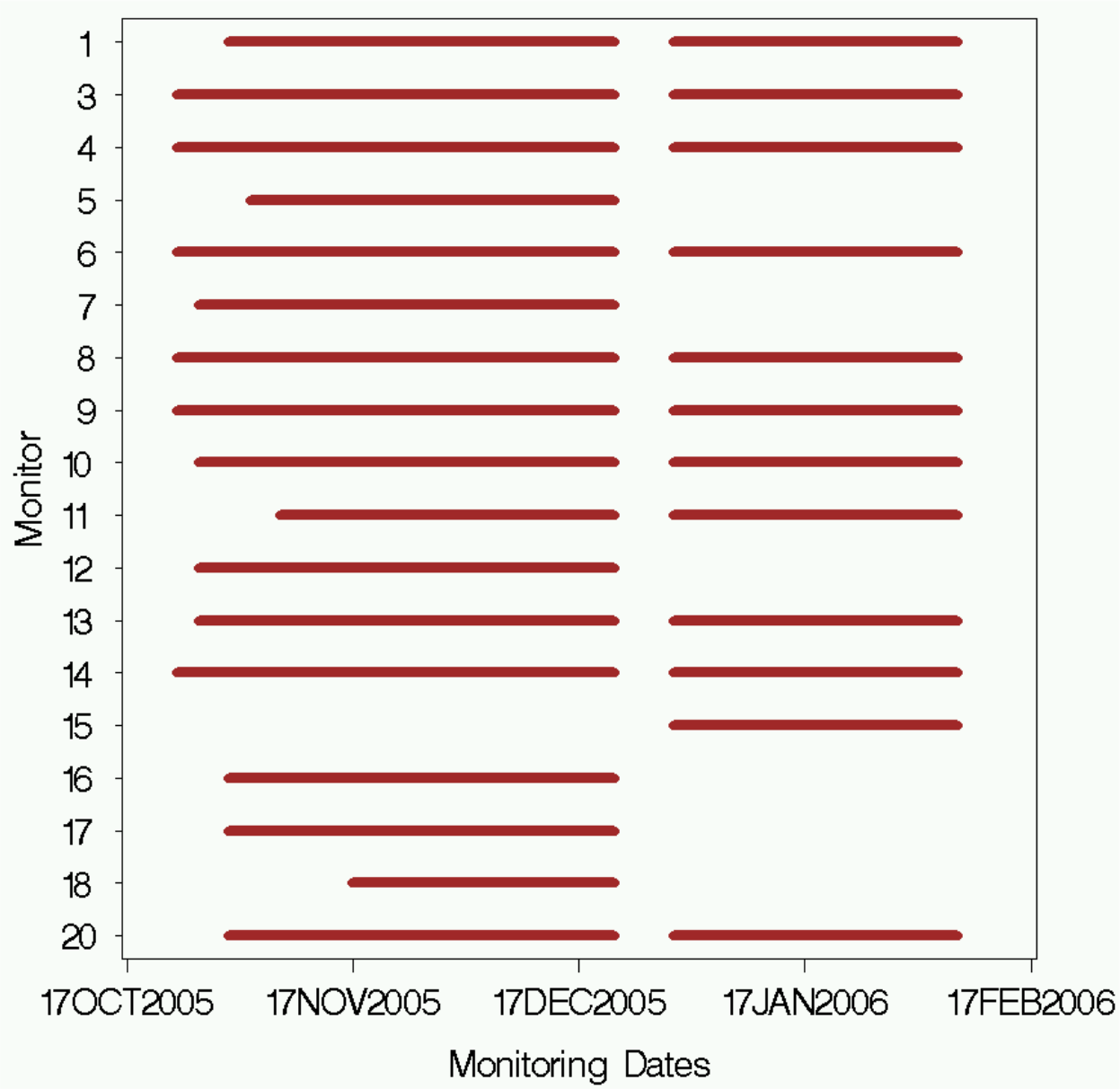

Figure 2. Post-Hurricane Katrina passive sampling dates.

IV. Results

The overriding conclusion from the passive OVM sampling conducted in the aftermath of Hurricane Katrina is that all monitored VOCs in the greater New Orleans area were found only at low levels, if at all. Indeed, almost all observed concentrations could be characterized as very low.

As mentioned above, different sites entered the sampling at different times. However, once sampling began, very few samples were missed. Data completeness was very high for all chemicals except β-pinene. For the other twenty-eight chemicals, there were 411 of a possible 416 valid observations; this gives a data completeness figure of 99%. An improper standard had been sent to the analytical laboratory, and this reduced the number of valid β-pinene observations to 300 and the data completeness to 72%.

As measured by the duplicate samples, precision was found to be quite good. Table 3 summarizes precision for the project by reporting for each chemical the median absolute and percentage differences from the duplicate samples. In addition, the maximum absolute difference is also reported. The maximum percentage difference observed is not reported because it was often distorted by one sample being below the analytical detection limit (*i. e.*, the chemical could not be detected at all) and the other being above this level; often, the higher value was still below the method detection limit (*i. e.*, the chemical was found to be present, but at a level too low to quantify). Table 3 indicates that over all chemicals the maximum observed difference in the duplicate samples was 1.81 $\mu g/m^3$ and the largest median was 0.31 $\mu g/m^3$, both for pentane. Note also that even with the very low levels observed during the study, the median percentage difference was 10% or higher only for seven chemicals.

Table 3. Differences from duplicate samples: median absolute, median percentage, and maximum absolute.

Compound	Median absolute ($\mu g/m^3$)	Median percentage	Maximum absolute ($\mu g/m^3$)
benzene	0.03	4	0.36
toluene	0.06	4	0.66
ethylbenzene	0.02	5	0.19
m,p-xylene	0.06	5	0.50
o-xylene	0.02	6	0.22
methyl tertbutyl ether (MTBE)	0	0	0
methyl ethyl ketone	0.06	7	0.86
carbon tetrachloride	0.03	4	0.16
methylene chloride	0.03	15	0.20
trichloroethylene	0	0	0.16
tetrachloroethylene	0	0	0.14
styrene	0	0	0.09
naphthalene	0	0	0.06
hexane	0.14	18	0.88
pentane	0.31	15	1.81
nonane	0.02	9	0.31
decane	0.01	2	0.56
methylcyclopentane	0.05	10	1.00
dimethylpentane	0	0	1.79
ethylmethylbenzene	0.04	8	0.24
1,2,3-trimethylbenzene	0.01	4	0.12
1,2,4-trimethylbenzene	0.02	6	0.18
1,3,5-trimethylbenzene	0.01	7	0.13
chloroform	0	0	0.26
p-dichlorobenzene	0.02	12	0.14
isoprene	0	0	0
α-pinene	0.04	15	0.31
β-pinene	0	0	0
d-limonene	0.05	24	0.56

Table 4 reports summary percentile statistics for all the VOCs monitored during the project; that is, these percentiles are calculated over all sites and all sampling periods. Before summary statistics were calculated, values that were reported as below the method detection limit were set to half the method detection limit, and duplicate samples were averaged. Values that appear as zeroes represent values that were below the analytical detection limit.

The major feature of Table 4 is that VOC concentrations were very low. The following observations illustrate this point.

(1) All the VOCs in the table have a 95^{th} percentile that is less than 5 $\mu g/m^3$.
(2) Isoprene was never detected in any sample.
(3) In addition to isoprene, the maximum observed values for tetrachloroethylene, naphthalene, *p*-dichlorobenzene, and d-limonene were all less than 1.0 $\mu g/m^3$.
(4) Only ten of the twenty-nine chemicals had maximum concentrations above 10 $\mu g/m^3$.

To elaborate on this last point, five of these ten compounds had only one observed value over 10 $\mu g/m^3$. Table 5 lists by compound all observations exceeding 10 $\mu g/m^3$; again, the table is based on data over all sites and sampling periods.

Though not apparent from Tables 4 or 5, it was found that one particular sample was responsible for many of the largest VOC values observed during the entire monitoring effort. This sample was from the second week of sampling for November 3-7, 2005 at Site 12-Bucktown Coast Guard Station. Over all sites and monitoring periods, this one sample generated:

(a) the maximum observed concentration for benzene, toluene, ethylbenzene, *m,p*-xylene, *o*-xylene, MTBE, hexane, methylcyclopentane, dimethylpentane, ethylmethylbenzene, and all three of the trimethylbenzenes;
(b) the second largest observed concentration for pentane and nonane;
(c) the third largest observed concentration for tetrachloroethylene and styrene;
(d) the fifth largest observed concentration for decane.

Listed in these points a-d are eighteen of the twenty-nine compounds measured, and many of these are fuel components. Based on Dr. Stock's observations from the Bucktown Coast Guard Station site visit, it seems likely that either refueling or, perhaps, a fuel spill influenced this particular sample; however, the sample's field notes did not mention either.

As a further indication of how low the chemical concentrations were during this post-hurricane monitoring, Table 6 reports the percentage of observations that were below the method detection limit (including below the analytical detection limit, as well). As can be seen from the table, thirteen of the twenty-nine compounds were less than the method detection limit in more than half of all samples.

Table 4. Percentiles (μg/m^3) from passive monitoring in the greater New Orleans area.

	Percentiles										
Compound	**Min**	**1**	**5**	**10**	**25**	**50**	**75**	**90**	**95**	**99**	**Max**
benzene	.24	.30	.40	.46	.58	.77	1.05	1.38	1.70	4.24	6.73
toluene	.24	.34	.43	.52	.74	1.20	1.87	2.84	3.48	6.69	27.09
ethylbenzene	.04	.05	.06	.09	.15	.26	.42	.64	.86	1.43	8.52
m,p-xylene	.11	.12	.18	.30	.45	.83	1.34	2.08	2.80	4.98	29.87
o-xylene	.06	.06	.07	.11	.19	.30	.48	.72	1.01	1.78	11.21
methyl tertbutyl ether (MTBE)	0	0	0	0	0	0	0	0	0	9.68	54.71
methyl ethyl ketone	.14	.20	.33	.38	.52	.66	.88	1.11	1.29	1.62	4.33
carbon tetrachloride	0	.40	.41	.43	.46	.50	.54	.59	.65	.84	4.01
methylene chloride	0	0	0	0	.02	.06	.11	.21	.31	.63	1.31
trichloroethylene	0	0	0	0	.03	.06	.08	.12	.20	.35	1.29
tetrachloroethylene	0	0	.04	.05	.06	.10	.13	.24	.34	.49	.95
styrene	0	0	0	0	0	0	.06	.15	.22	.49	1.13
naphthalene	0	0	0	0	0	0	0	0	0	.41	.80
hexane	0	0	0	0	0	.47	.88	1.30	2.05	6.50	13.51
pentane	0	0	0	0	.98	1.62	2.45	3.39	4.63	9.70	40.74
nonane	0	0	0	0	0	.16	.27	.40	.48	1.05	2.44
decane	0	0	0	0	.10	.20	.44	.70	.92	1.72	1.96
methylcyclopentane	0	0	0	0	0	.36	.58	.93	1.21	2.43	10.38
dimethylpentane	0	0	0	0	0	0	0	.52	.76	2.07	5.00
ethylmethylbenzene	0	0	.06	.14	.22	.37	.59	.84	1.04	1.59	13.71
1,2,3-trimethylbenzene	0	0	0	0	0	0	.12	.19	.22	.36	2.35
1,2,4-trimethylbenzene	.06	.08	.12	.13	.20	.31	.50	.73	.92	1.64	11.97
1,3,5-trimethylbenzene	0	0	0	.04	.06	.08	.18	.26	.31	.55	4.00
chloroform	0	0	0	0	0	0	0	.12	1.22	3.58	4.84
p-dichlorobenzene	0	0	0	0	.04	.05	.08	.14	.20	.33	.72
isoprene	0	0	0	0	0	0	0	0	0	0	0
α-pinene	0	0	.06	.12	.22	.34	.57	1.65	2.86	7.08	12.00
β-pinene	0	0	0	0	0	0	0	.42	.78	1.98	3.53
d-limonene	0	0	0	0	.06	.10	.16	.26	.34	.67	.90

Table 5. All observed passive sampling concentrations above 10 μg/m^3.

Compound	**Observed values > 10 μg/m^3**			
toluene	27.09	10.54		
m,p-xylene	29.87			
o-xylene	11.21			
methyl tertbutyl ether (MTBE)	54.71	14.92	13.26	10.20
hexane	13.51	13.29		
pentane	40.74	23.03	12.24	11.28
methylcyclopentane	10.38			
ethylmethylbenzene	13.71			
1,2,4-trimethylbenzene	11.97			
α-pinene	12.00	11.43	10.17	

Table 6. Percentages of observations below the method detection limit.

Compound	Percentage
benzene	0
toluene	0
ethylbenzene	13
m,p-xylene	12
o-xylene	6
methyl tertbutyl ether (MTBE)	97
methyl ethyl ketone	9
carbon tetrachloride	0
methylene chloride	64
trichloroethylene	81
tetrachloroethylene	68
styrene	81
naphthalene	99
hexane	39
pentane	21
nonane	46
decane	61
methylcyclopentane	36
dimethylpentane	92
ethylmethylbenzene	7
1,2,3-trimethylbenzene	68
1,2,4-trimethylbenzene	2
1,3,5-trimethylbenzene	47
chloroform	90
p-dichlorobenzene	73
isoprene	100
α-pinene	15
β-pinene	82
d-limonene	70

Hurricane Katrina affected a much larger area than just the city of New Orleans itself. Accordingly, the air quality sampling was designed to ascertain air quality levels in the greater New Orleans area. To assess whether sections of the area were differentially impacted in terms of their air quality, the geographic region was subdivided into four different areas: Area 1 – to the west around Kenner, containing four sampling sites; Area 2 - in and around central New Orleans with seven sites; Area 3 - just east of the city with three sampling sites; and Area 4 – with four sites around the northeastern end of Lake Ponchartrain. Figure 1 delineates these divisions and the sampling sites within them.

As the above discussion implies, monitored levels of the VOCs were generally so low that differences of large magnitude were not apparent between the different areas. Plots of the observed values are illustrated in Figures 3, 4, 5, and 6 for pentane, hexane, benzene, and toluene, respectively.

To illustrate the body of the observed values in each case, these figures have been restricted to eliminate the higher concentrations observed (Table 4); however, the vertical axis of each graph does exceed the 95th percentile for each species (Table 4). These box and whisker plots show the 25th and 75th percentiles (the bottom and top of each box) and the median (the line through the box). Below the box, the whiskers extend to the minimum observed value. Above the 75th percentile, the whiskers extend for a length equal to 1.5 times the interquartile range (*i. e.*, the distance between the 25th and 75th percentiles) or to the maximum observed value for the area, whichever is less. If chemical concentrations in an area were observed that were higher than the terminus of a whisker, these individual values appear above the box and whisker plot.

These plots suggest that concentrations were slightly lower in the two easternmost areas, 3 and 4. Indeed, statistical testing showed that this was generally the case for Area 4. However, Area 3 was found to be lower in concentration for only a few species. The testing was done on the median values from each site. First, the Kruskal-Wallis test was used to check for evidence of some difference(s) among the four areas. For those compounds for which the Kruskal-Wallis test was significant, the two-sided Wilcoxon rank sum test was used to make pairwise comparisons between the areas. All testing was done at the 5% significance level. Descriptions of the Kruskal-Wallis and Wilcoxon tests may be found in textbooks on nonparametric statistics (*e. g.*, Hollander and Wolfe, 1999). Table 7 reports the results of these statistical comparisons.

For eleven of the twenty-nine compounds, the Kruskal-Wallis test found no significant difference among the areas. For the other eighteen chemicals, the Wilcoxon test found that Area 4 (the northeastern end of Lake Ponchartrain) had lower concentrations than did Area 2 (central New Orleans). In addition, fifteen of these species were found to have lower levels in Area 4 than in Area 1 (west of New Orleans, around Kenner). However, Area 3 was not generally found to have statistically significant differences in concentrations than the other areas. Note that these statistical testing results should be interpreted in light of the fact that the concentrations in all parts of the greater New Orleans area were very low.

Another question of interest was whether any of the areas exhibited increasing or decreasing trends in chemical concentrations during the sampling. This aspect of the post-hurricane environment was addressed using the Mann-Kendall trend test (Hollander and Wolfe, 1999). The test was applied to the observed medians for each area from each weekly report; all testing was done at the 5% significance level. Only seven statistically significant trends were found: three uptrends and four downtrends. The magnitude of the trends was gauged by the Sen-Theil estimator (Theil, 1950; Sen, 1968). Table 8 reports these results.

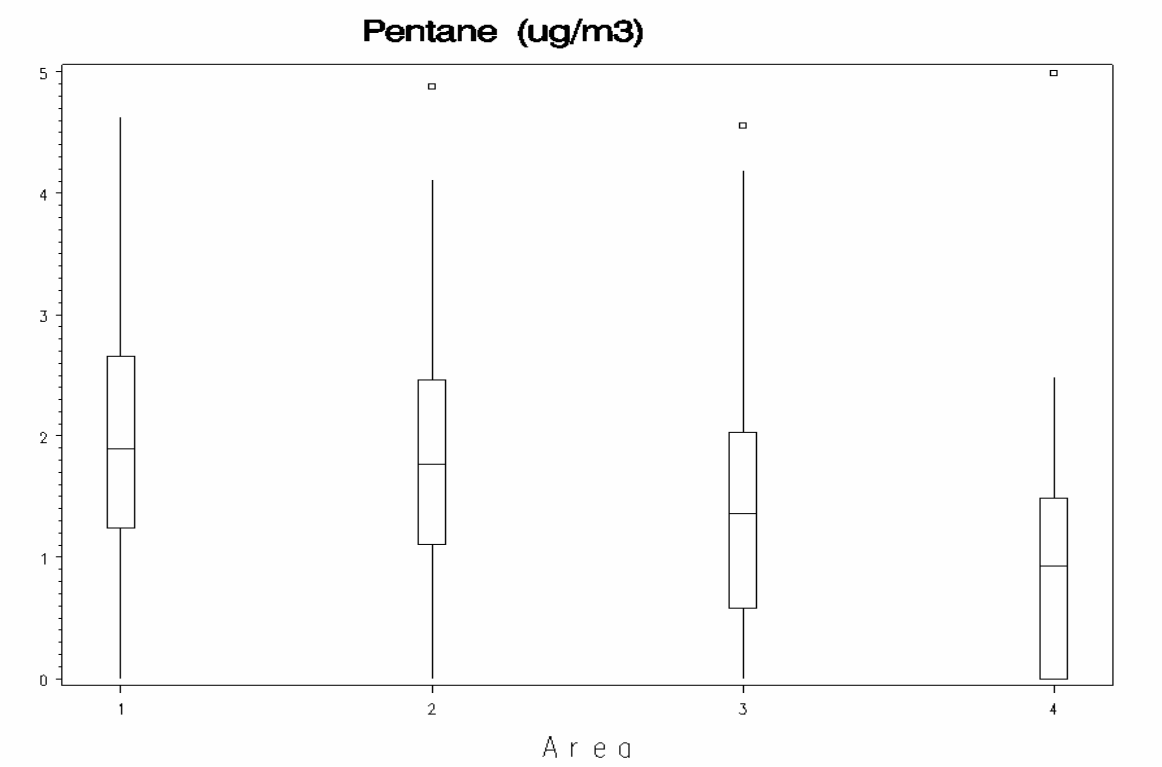

Figure 3. Observed pentane values by area.

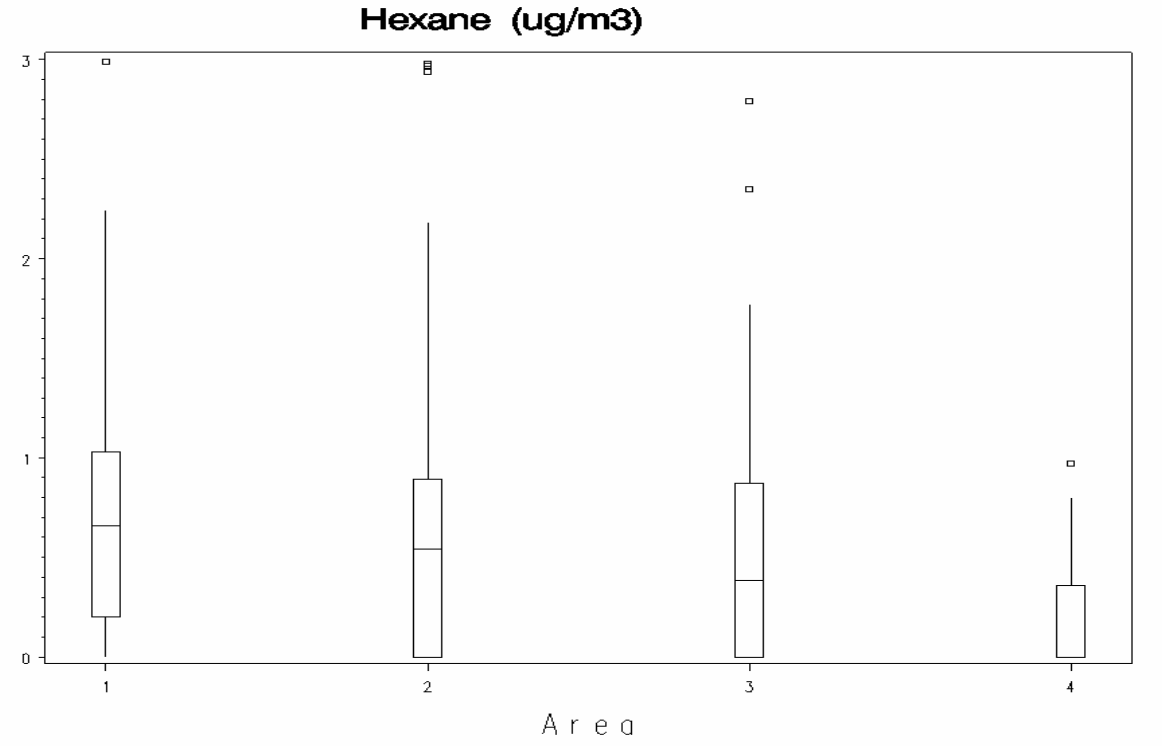

Figure 4. Observed hexane values by area.

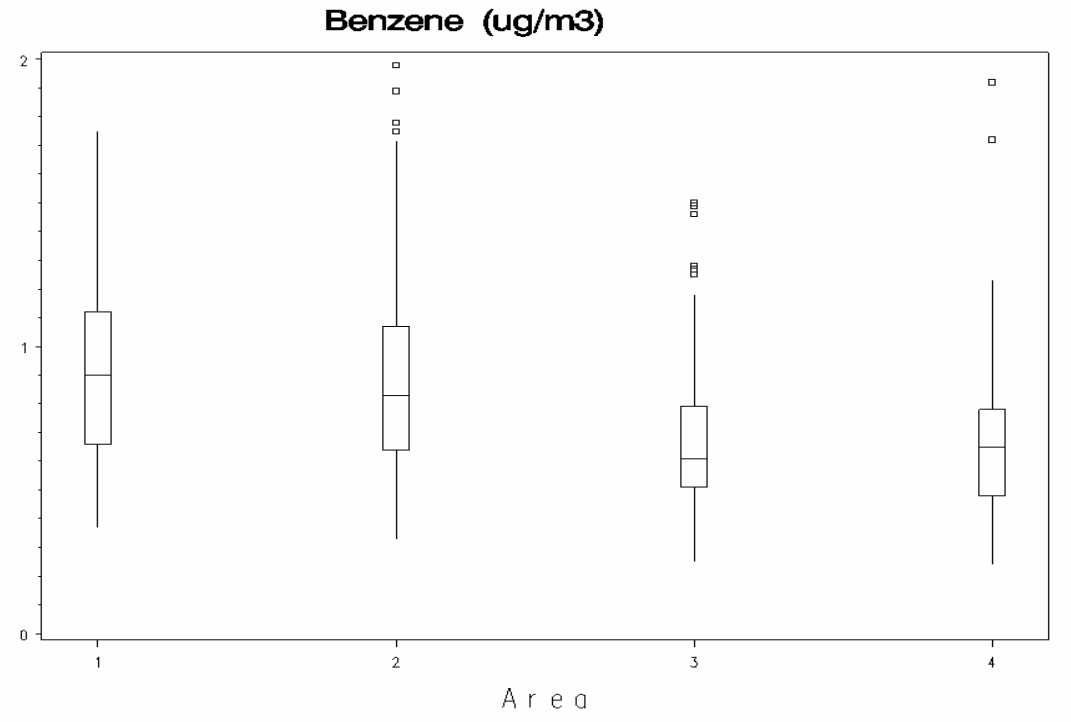

Figure 5. Observed benzene values by area.

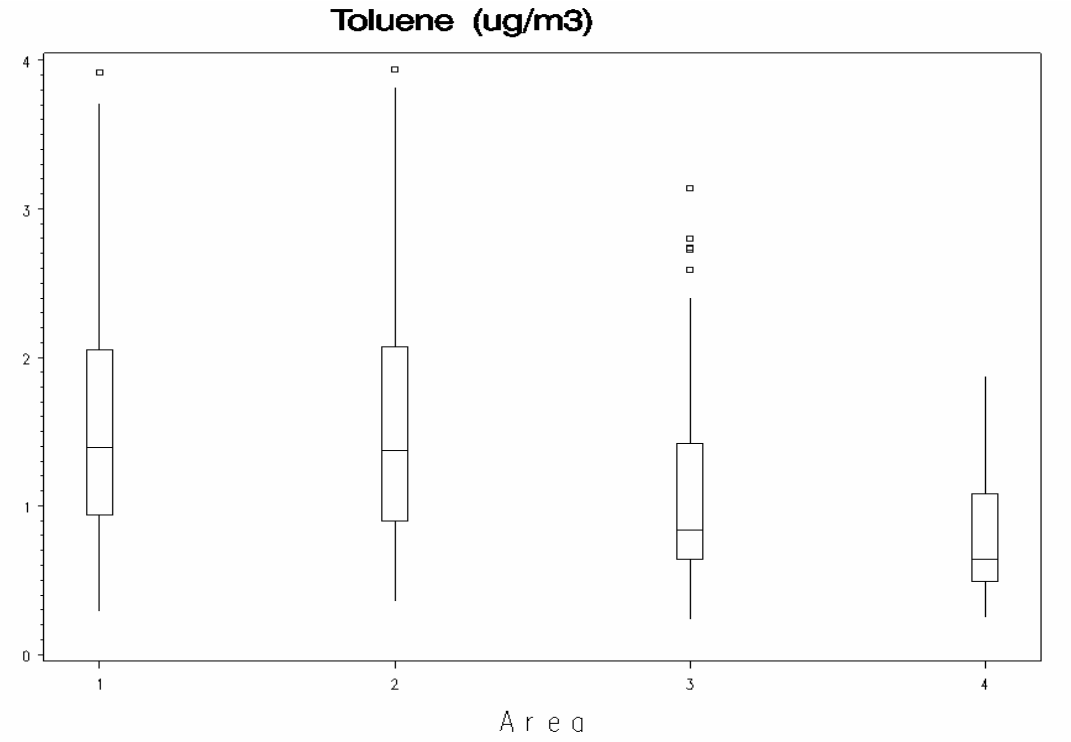

Figure 6. Observed toluene values by area.

Table 7. Statistical comparisons of areas (5% significance level).

Compound	**Kruskal-Wallis significant?**	**Wilcoxon tests for area comparisons**					
		1 *vs.* 2	**1 *vs.* 3**	**1 *vs.* 4**	**2 *vs.* 3**	**2 *vs.* 4**	**3 *vs.* 4**
benzene	Yes				3 < 2	4 < 2	
toluene	Yes			4 < 1		4 < 2	
ethylbenzene	Yes			4 < 1	3 < 2	4 < 2	
m,p-xylene	Yes			4 < 1	3 < 2	4 < 2	
o-xylene	Yes			4 < 1		4 < 2	
methyl tertbutyl ether (MTBE)	No	--	--	--	--	--	--
methyl ethyl ketone	Yes			4 < 1		4 < 2	
carbon tetrachloride	Yes					4 < 2	
methylene chloride	No	--	--	--	--	--	--
trichloroethylene	Yes			4 < 1		4 < 2	
tetrachloroethylene	Yes			4 < 1		4 < 2	
styrene	No	--	--	--	--	--	--
naphthalene	No	--	--	--	--	--	--
hexane	Yes			4 < 1		4 < 2	4 < 3
pentane	Yes			4 < 1		4 < 2	
nonane	Yes			4 < 1		4 < 2	
decane	Yes					4 < 2	
methylcyclopentane	Yes			4 < 1		4 < 2	4 < 3
dimethylpentane	No	--	--	--	--	--	--
ethylmethylbenzene	Yes			4 < 1	3 < 2	4 < 2	
1,2,3-trimethylbenzene	No	--	--	--	--	--	--
1,2,4-trimethylbenzene	Yes			4 < 1		4 < 2	
1,3,5-trimethylbenzene	Yes			4 < 1		4 < 2	
chloroform	No	--	--	--	--	--	--
p-dichlorobenzene	Yes			4 < 1	3 < 2	4 < 2	
isoprene	No	--	--	--	--	--	--
α-pinene	No	--	--	--	--	--	--
β-pinene	No	--	--	--	--	--	--
d-limonene	No	--	--	--	--	--	--

Key:
-- means that no Wilcoxon test was done since the Kruskal-Wallis test was not significant.
A blank entry means the Wilcoxon test was not significant at the 5% level.
A non-blank entry indicates which area was lower based on a significant Wilcoxon test.

Table 8. Statistically significant (5%) time trends from post-Hurricane Katrina sampling.

Compound	Area	Direction	Estimated magnitude ($\mu g/m^3$/period)
hexane	3	up	0.05
styrene	1	down	-0.001
α-pinene	3	down	-0.04
α-pinene	4	up	0.20
1,2,3-trimethylbenzene	1	down	-0.01
1,2,3-trimethylbenzene	2	down	-0.01
d-limonene	4	up	0.02

V. Conclusion

From October 24, 2005 through February 7, 2006 in the aftermath of Hurricane Katrina, twenty-nine VOCs were measured at eighteen passive monitoring sites in the greater New Orleans area. The area around the northeastern end of Lake Ponchartrain recorded relatively lower concentrations of most compounds than either the central area of New Orleans or the area just west of the city. Only a few statistically significant time trends were observed from the monitoring.

However, the overriding result from this monitoring was that all chemicals were found only at low levels -- indeed generally at very low levels. In fact, many VOCs were often reported to be less than the method detection limit, or even less than the analytical detection limit.

VI. References

Chung, C.-W., M. T. Morandi, T. H. Stock, and M. Afshar, 1999, Evaluation of a passive sampler for volatile organic compounds at ppb concentrations, varying temperatures, and humidities with 24-hr exposures. 2. Sampler performance. *Environ. Sci. Technol.* 33:3666-3671.

Chung, K. C., T. H. Stock, M. T. Morandi, and M. Afshar, 2004, "Evaluation and use of diffusive air samplers for determining temporal and spatial variation of volatile organic compounds in the ambient air of urban communities" in *Proceedings of the 97th Annual Conference of the Air and Waste Management Association*, June 2004, Indianapolis, IN.

Hollander, M. and D. A. Wolfe, 1999, *Nonparametric Statistical Methods*, John Wiley and Sons, New York, 787 pp.

Morandi, M. T. and T. H. Stock, 1997, *Personal Exposures to Toxic Air Pollutants. Feasibility Study: Results of Field Pilot Exposure Study, and Modification of the 3500 OVM Passive Dosimeter (Vol. 2)*, Mickey Leland National Urban Air Toxics Research Center, Houston, TX.

Sen, P. K., 1968, Estimates of the regression coefficient based on Kendall's tau, *J. Amer. Statist. Ass.* 63:1379-1389.

Stock, T. H. and M. T. Morandi, 1996, *Personal Exposures to Toxic Air Pollutants. Feasibility Study: Laboratory Evaluation and Field Method Comparison (Vol. 1)*, Mickey Leland National Urban Air Toxics Research Center, Houston, TX.

Theil, H., 1950, A rank-invariant method of linear and polynomial regression analysis III. *Proc. Kon. Ned. Akad. v. Wetensch.* 53:1397-1412.